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Factors that predispose hamstring muscle strain

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FACTORS THAT PREDISPOSE HAMSTRING MUSCLE STRAIN

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ABSTRACT

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This review of literature examined the etiological factors that are associated with hamstring muscle strain. The purpose was to determine which factors predispose athletes to hamstring muscle strain. It consisted of articles and studies reviewed for factors of flexibility, strength, hamstring/quadriceps ratio, and eccentric muscle contraction. Additional factors reviewed included the effects of fatigue, warmup conditions, running style, posture, and anatomical and psychological factors.

From an analysis of the literature, the factors and their contribution to hamstring muscle strain were identified. No single factor appears to predispose an athlete to hamstring muscle strain; rather, factors may work in conjunction. Athletic trainers, physical therapists, and coaches must assess athletes in regards to the factors that may predispose them to hamstring muscle strain. Many of the factors that contribute to hamstring muscle strain can be reduced and corrected; however, injury may still occur. This study enhances the understanding of contributory factors that predispose an athlete to hamstring muscle strain and has developed a "Prescription for Hamstring Muscle Strain Prevention."

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CHAPTER I

INTRODUCTION

Background of Study

In athletics, the potential for injury is high. Once injured, a players' participation time is reduced. Careful attention to correcting predisposing factors is clearly an important recommendation for injury prevention. Hamstring strain, often referred to as a "pulled hamstring," is an injury commonly seen by athletic trainers, physicians, coaches, and athletes (Sutton, 1984). This injury can be devastating to an athlete because it often heals slowly and has a tendency to recur (Agre, 1985). Hamstring muscle strain can persist throughout a sports season and lead to chronic conditions that shorten an athlete's career.

Many authors have examined the factors associated with the cause of hamstring muscle strain. O'Neil (1976) noted causes such as fatigue, poor posture, uneven muscle strength, nonflexibility, and overstretching. According to Shankman (1993), fatigue, tightness, improper warmup, quadriceps/hamstring ratio imbalance, poor running mechanics, and lack of calcium and magnesium are factors associated with hamstring muscle strain. Agre (1985) stated that flexibility, inadequate strength and/or endurance, dys-synergetic contraction, insufficient warmup, poor running style, and premature return to sports following injury may predispose an athlete to hamstring muscle strain.

Muckle (1982) examined associated factors in recurrent groin and hamstring injuries, which should be considered in diagnosis before therapy begins. He associated lumbo-sacral problems, such as mild lumbar disc lesion at the fourth/fifth lumbar or fifth lumbar/first sacral levels, facet joint arthrosis, or spondylolysis with the recurrent hamstring injury. According to Muckle (1982), other factors associated with recurrent hamstring injuries, include knee meniscal problems, adhesion of the lateral popliteal nerve, abnormal quadriceps power, enthesopathies (gout), ankylosing spondylitis, Reiter's syndrome, and sero-negative spondarthritides.

Justification of Study

There is conflicting scientific information regarding the etiology of hamstring muscle strain. This creates an atmosphere of confusion for the medical practitioner who is trying to treat and rehabilitate these afflictions. Sports medicine practitioners agree that hamstring muscle strain is a complex injury that involves more than one etiological factor (Worrell & Perrin, 1992). By examining the causative factors in the literature, this study employs a multifactor approach in the understanding of this problem. This study examines the primary factors of flexibility and muscle strength, as well as the mechanical, physiological, and psychological factors leading to hamstring muscle strain. In addition, this study examines the potential effects of secondary factors such as fatigue, running style, and posture.

Although research has shown that there may be several causes predisposing athletes to hamstring strain, a commonality does exist in many factors causing this injury. For example, flexibility is identified as one factor leading to hamstring muscle strain. Studies investigating this factor identified hypoflexibility of the hamstring muscles as a leading cause of injury. Worrell, Perrin, Gansneder, and Gieck (1991) found that subjects with hamstring injury were significantly less flexible compared to the noninjured group. Jonhagen, Nemeth, and Eriksson (1994) described the factor of hypoflexibility leading to hamstring muscle strain in their study which examined sprinters with hamstring injuries.

Along with flexibility, Worrell et al. (1991) studied several hamstring muscle strength indices and ratios between injured and noninjured athletes. Their results indicated no significant strength differences between injured and noninjured athletes. Burkett (1970) showed how strength differences could allow practitioners to accurately predict subjects who may suffer a hamstring muscle strain. The conflicting results of these studies suggest that additional research is necessary to identify the critical factors leading to hamstring muscle injuries.

Statement of the Purpose

Over the past 25 years, many investigators (Appendix A), conducted research studies investigating various factors that may lead to hamstring muscle strain. Most studies identified the factors that predispose an athlete to hamstring muscle strain, however, there are no current or recent reviews of the literature that thoroughly examine the identified factors. In an attempt to fill the void, the purpose of this study was to investigate current and past literature to determine the factors, causes, and contributions to hamstring muscle strain. This study reviewed the research to determine which relationships appear to affect hamstring muscle strain and to provide a prescription for prevention of hamstring muscle strain based on the evidence provided through the literature.

Assumptions

There are two assumptions for this study. One assumption is the researcher thoroughly studied all major factors associated with this injury by collecting and analyzing applicable data. The second assumption is that this study includes an adequate review of all the available articles reporting recent and current research resulting in a comprehensive discussion of the literature.

Delimitations of Study

There are several delimitations in this study of hamstring muscle strain. One delimitation was that all articles reviewed were in the English language. This study included articles published in journals available in university libraries in California and through the national interlibrary loan system. Another delimitation of this study, was that it only investigated isolated hamstring strain from a relatively healthy population. Reviewed articles encompassed the period from 1970 through 1994.

Limitations of Study

Limitations of this study included possible factors associated with hamstring muscle injury and other potential factors not yet researched. Articles written in other than the English language and not translated were not included in this review. Articles not discussed in this investigation included articles published before 1970 and after December 1994. Finally, there may be articles not discussed in the paper and not included in the CD-ROM databases such as studies not published in major journals. In addition, there may be articles that were not found through the process of cross-referencing of references.

Definitions

Active knee extension (AKE) test: A test of hamstring muscle length in which the knee is actively extended while the hip is maintained in a flexed position of 90 degrees (Coole & Gieck, 1987, p. 80).

Athletic injury: Disruption in tissue continuity that results from athletic activity and causes a cessation of participation or restriction of usual activity (Booher & Thibodeau, 1985, p. 574).

Concentric contraction: When a muscle develops tension sufficient to overcome a resistance, so that the muscle visibly shortens and moves a body part (Rasch & Burke, 1978, p. 50).

Eccentric contraction: When a given resistance overcomes the muscle tension so the muscle actually lengthens (Rasch & Burke, 1978, p. 50).

Flexibility: The range of movement of a specific joint or group of joints influenced by the associated bones and bony structures as well as the physiological characteristics of the muscles, tendons, ligaments, and the various other collagenous tissues surrounding the joint (Arnheim & Prentice, 1993, p. 86).

Hamstring muscles: A group of muscles posterior to the thigh that runs from the buttocks to the posterior knee. The hamstring muscles consist of the biceps femoris, semitendinosus, and semimembranosus muscle. Their primary functions are to flex the knee and to extend the hip (Coole & Gieck, 1987, p. 80).

Isokinetic muscle testing: Measurement of torque generated while keeping the limb in motion at a constant, predetermined velocity while applying accommodating resistance throughout the range of motion (Biodex Corporation, 1991).

Isometric muscle testing: A measurement of the strength of contraction in which the muscle is in a static position with no change in the length of the muscle or angle of the joint in which the contraction takes place (Arnheim & Prentice, 1993, p. 83).

Passive knee extension (PKE) test: A measurement of hamstring muscle length in which the knee is passively extended while the hip is maintained in a flexed position of 90° (Worrell, Perrin, Gansneder, & Gieck, 1991, p. 119).

Straight leg raise (SLR) test: An examination wherein muscle length is measured indirectly by angular measurement of unilateral hip flexion with the knee extended (Wang, Whitney, Burdett, & Janosky, 1993, p. 103).

Strain: Injury resulting from a pull, stretch, or rip of a muscle or tendon that causes various degrees of stretch or tear to the muscle, tendon, or adjacent tissue (Arnheim & Prentice, 1993, p. 216).

Tendon: A band or cord of fibrous connective tissue that attaches a muscle to a bone or other structure (Booher & Thibodeau, 1985, p. 584).

CHAPTER II

PROCEDURES AND METHODOLOGY

There is increased emphasis being placed on injury prevention in modern medicine. However, athletic trainers, physical therapists, and sports medicine practitioners are constantly seeking ways to improve on current methods of treating athletic-related injuries. One injury of significance to athletes is hamstring muscle strain. Understanding the factors that predispose an athlete to hamstring muscle strain can promote better prevention strategies and reduce the time an athlete may not participate.

The purpose of this study was to investigate the current and past literature to determine associated factors and contributions to hamstring muscle strain. This study reviewed available research to determine which relationships appear to affect hamstring muscle injury.

A search of the literature was conducted at the Clark Library on the campus of San Jose State University using CD-ROM or compact disks. The computer search examined the SPORT, ERIC, and MEDLINE databases. These databases referenced practical and researched literature from around the world. The databases available on compact disk contained bibliographic references to published information (periodical articles, books, theses, conference proceedings, and research) on sports medicine, exercise physiology, physical fitness, sports science, sports psychology, and biomechanics (Sport Database, 1993).

The SPORT DISCUS database covers practical and research literature dealing with all sport and fitness disciplines. Coverage includes over 1,000 international sport periodicals, as well as many medical and related journals.

SPORT DISCUS contain over 270,000 individual referenced sources beginning in 1975, with thesis and monograph coverage going back to 1949. The ERIC database pertains to the topics of education at all levels and corresponds to two print publications: *Resources in Education (RIE)* and *Current Index to Journals in Education (CIJE)*. MEDLINE indexes approximately 3,200 worldwide journals in medicine and other allied healthcare disciplines beginning in 1988. It corresponds to the *Index Medicus* (CD-ROM Point of Use Guides-Manual, San Jose State University, 1992).

Additional information was obtained from the reference section of each article through the process of cross-checking. Cross-checking is a process in which the reference section of each article is examined for related articles which are then searched. This allowed specific sources related to searched materials to be reviewed and spanned a variety of periodical sources. A chart, "Summary of Topics Discussed in Recent Studies By Author (1970-1994)," was developed to display the frequency of factors in the literature (Appendix A).

The majority of the referenced articles acquired in this initial investigation were from the libraries on the campuses of San Jose State University and Stanford University. The Stanford Medical School Library and the interlibrary loan provided several articles. The final method of reference searching included personal periodicals gathered from athletic training authorities who have access to studies unavailable at previously mentioned sources. These references were copies of the full original articles, abstracts, and bibliographies.

The articles were reviewed and examined for content that would enhance the understanding of the factors that are associated with hamstring muscle strain. The criteria for inclusion were that (a) the article or study describe the factor's contribution to hamstring muscle injury, (b) the study's approach was scientific in nature and conducted on normal subjects, and (c) the article or study would examine the factor(s) for any relationships that could predict its ability to predispose hamstring muscle strain.

Based on my review of the literature and to enhance the understanding of the factors that predispose an athlete to hamstring muscle strain, "Prescription for Hamstring Muscle Strain Prevention" was developed. It includes the factors that predispose athletes to hamstring muscle strain and a systematic way to examine and correct any deficiencies related to injuries of the hamstring muscles. The "Prescription for Hamstring Muscle Strain Prevention" suggest how to perform tests that assess a factors contribution to muscle strain, determines what results should be observed with test performance, and gives an implementation that may reduce or correct a factor's contribution to hamstring muscle strain. This is solely a recommendation based on the investigator's perception.

CHAPTER III

REVIEW OF LITERATURE: FACTORS LEADING TO HAMSTRING MUSCLE STRAIN

Researchers often study the factors that predispose an athlete to injury. Much of the literature investigates only a single factor without examining the problem as a whole. This chapter examines the past and current literature and describes the anatomy and function of the muscle group known as the hamstrings. This chapter also presents an analysis of the various factors that predispose an athlete to hamstring muscle strain.

Anatomy

The hamstring muscle group is one of the most complex muscle groups in the human body due to its role in both locomotion and stability of the lower extremities. The hamstring muscle group spans the hip to the posterior aspect of the knee. The hamstring group consists of three muscles—semitendinosis, biceps femoris, and semimembranosus—with some research indicating a fourth, the adductor magnus (Casperson & Kaverman, 1982).

Semitendinosus

The semitendinosus, situated at the posterior and medial space of the thigh, is remarkable for the great length of its tendon (Gray, 1977). The semitendinosus originates from the ischial tuberosity, where it shares fibers with the biceps femoris. This muscle separates as it passes down the posteromedial aspect of the thigh to the knee where it inserts on the anterior medial aspect of the tibial condyle. There the semitendinosus shares its insertion with the sartorius and gracilis to form the pes anserine group. The semitendinosus muscle functions to flex and medially rotate the knee as well as to extend, medially rotate, and adduct the hip (Coole & Gieck, 1987). This hamstring muscle is innervated by two branches of the tibial portion of the sciatic nerve. In addition, there are fibers that come from the fifth lumbar and first and second sacral nerves (Rasch & Burke, 1978).

Biceps Femoris

The biceps femoris, situated on the posterior and lateral aspect of the thigh, is a large muscle of considerable length (Gray, 1977). This hamstring muscle has two heads: the long head extends inferior and laterally from the ischial tuberosity, and the short head originates from the lateral tip of the linea aspera (Casperson & Kaverman, 1982). Distally, the two muscles share a common tendon and insert on the head of the fibula and lateral tibial condyle, with some fiber attachment to the iliotibial band and posteriolateral joint capsule of the knee (Coole & Gieck, 1987).

The biceps femoris muscle is unique in its function. The short head functions to flex the knee (Casperson & Kaverman, 1982). However, the long head of the biceps femoris muscle produces hip extension and adduction along with knee flexion. The two muscles together function as lateral rotators of the hip. In addition, they tighten the posterior lateral aspect of the knee due to their broad insertion. Each head of the biceps femoris muscle has separate nerve innervation, a factor that may lead to muscle strain (Coole & Gieck, 1987). In a computed tomographic study of hamstring muscle strains (Garrett, Rich, Nikolaou, & Vogler, 1989), the proximal portion of the biceps femoris long head was the site of strain in five out of ten hamstring muscle strains.

Simultaneous contraction of the quadriceps and the short head of the biceps femoris, along with the dual innervation of the biceps femoris muscle, pose a neural mechanism for injury (Casperson & Kaverman, 1982). This notion of dual innervation is supported by Shankman (1993). The long head receives its nerve supply from two branches of the tibial division of the sciatic nerve and contains fibers from the first, second, and third sacral nerves (Rasch & Burke, 1978). The short head is innervated by the peroneal portion of the sciatic nerve and contains fibers from the fifth lumbar and the first and second sacral nerves (Coole & Gieck, 1987).

<u>Semimembranosus</u>

The semimembranosus muscle, situated at the posterior and medial aspect of the thigh, is named for its membranous tendon of origin (Gray, 1977). This muscle originates from the ischial tuberosity and runs deeper than the other hamstring muscles to its distal insertion where it inserts by way of a thick rounded tendon to the posteromedial tibia. The tendon also has fibers attached to the posterior horn of the medial meniscus that causes the meniscus to draw posterior during knee flexion to prevent impingement. The semimembranosus also provides knee flexion, hip extension, and hip rotation (Coole & Gieck, 1987). This hamstring muscle is innervated by the tibial portion of the sciatic nerve. The semimembranosus contains fibers from the fifth lumbar and first two sacral nerves (Rasch & Burke, 1978).

<u>Adductor Magnus</u>

The adductor magnus, considered by some part of the hamstring muscle group, originates from the ischial tuberosity and runs distally and inserts on the adductor tubercle of the distal femur (Casperson & Kaverman, 1982). It is considered a member of the hamstring muscle group due to the action of the posterior portion of this adductor muscle. The adductor magnus performs hip extension and adduction and serves as a rotator of the hip. This is the only hamstring muscle that does not cross the knee which prevents it from acting on the knee (Coole & Gieck, 1987). This muscle is innervated by branches from the posterior division of the obturator nerve which contains fibers from the third and fourth lumbar nerves (Rasch & Burke, 1978).

Summary

The hamstring muscle group consists of three biarticular muscles that are movers and stabilizers of the hip. The three muscles are the biceps femoris, semitendinosus, and the semimembranosus with some literature citing a fourth hamstring muscle, the adductor magnus. When there is extension of the hip and flexion of the knee at the same time, both movements are weak (Thompson, 1981).

Hamstring Muscle Group Function

Stanton and Purdam (1989) examined the function of the hamstring muscle group and discussed their three basic functions. First, the hamstrings work eccentrically to decelerate the thigh and lower leg during the last part of the swing phase, stopping at approximately 30° from terminal knee extension. At this point, the muscles store elastic energy recovered during the early stance phase. Second, through concentric contraction during foot strike, the hamstrings assist in extending the hip while adding to the stability of the knee by preventing extension. In addition, the hamstrings function with the gluteal and quadriceps muscles during the early stance to absorb down forces six to seven times the body weight. Third, the hamstrings assist the quadriceps in achieving push-off.

In the last 15° to 20° of knee extension, the hamstrings are powerful extensors of the knee when the foot is in contact with the ground (Klein, 1971).

During the initial 20° of knee flexion, the mechanical efficiency of the quadriceps in extending the knee decreases. This results in a synergistic action of the gastrocnemius and hamstrings, creating a paradoxical extension movement at the knee during the last part of the stance phase. Liemohn (1978) noted this biomechanical action in his study of track athletes. He stated that the hamstrings are antagonistic to the quadriceps during the first 160° to 165° of leg extension. During these last few degrees that the hamstrings support the quadriceps in paradoxical extension.

There are other functions of the hamstring muscles noted in the literature. Hamstring muscle activity also protects the knee from hyperextension injury (Stanton & Purdam, 1989). In addition, the medial hamstrings play an important role in controlling and slowing the external rotation of the tibia (Klein, 1971).

Cinematographic recordings by Simonsen, Thomsen, and Klausen (1985) examined monoarticular and biarticular leg muscles during sprinting. They filmed and computer digitized four male national class sprinters running on a synthetic track. While filming, researchers obtained electromyographic signals synchronously recorded using surface electrodes located on nine muscles.

Results of the study by Simonsen et al. (1985) showed three different aspects of function of the biarticular hamstring muscles. These muscles function during both flight and recovery phase. The hamstrings perform eccentric activity during the swing phase and concentric activity during the ground support phase. The paradoxical muscle action that takes place around the knee joint was also evident. Research performed by Stanton and Purdam (1989) support the results of the study by Simonsen et al., by showing that the biarticular muscle exhibits greater variation and rate of variation in muscle length with activity.

Epidemiology

Studies often examine the rate of injury in athletics. A study by Seward, Orchard, Hazard, and Collinson (1993) determined injury profiles for elite-level competitors of Australian football. Over the 1992 season, researchers recorded 2,398 injuries in Australian Rules Football and in two Rugby leagues. The researchers surveyed the doctors who treated those injuries to examine the prevalence of injuries and the resulting time missed by players. In Australian Rules Football, hamstring muscle tears made up 13% of the total injuries sustained by participants and accounted for the most time missed from activity.

A study conducted by Lysholm and Wiklander (1987) examined the incidence of injury in relation to training exposure, probing for injury factors in 60 runners of an athletic club (44 men, 16 women). The runners recorded training and competition activities and reported injuries. Study results indicated that hamstring strains were more common in sprinters than in middle- and long-distance runners. The authors concluded the hamstring muscle group is more important in fast running and thus more prone to injury when speed is paramount. This was due to the fact that in this study of runners, sprinters sustained significantly more strains of the hamstrings than runners of other categories.

Factors Leading to Hamstring Muscle Strain

Flexibility

There is no question that flexibility plays an important role in hamstring muscle strain. The ability of muscle and connective tissue to absorb force is related to the muscle's resting length. The greater the resting length of the muscle, the greater the ability to absorb force and avoid strain (Worrell & Perrin, 1992).

Methods for assessing flexibility, however, may conflict with each other. Some studies use the Well's sit-and-reach method, and others use the straight leg raise test. The sit-and-reach test, one of the oldest tests for measuring flexibility, is performed from a sitting position with the subject reaching as far forward (toward the toes) as possible. Flexibility of the upper extremity and lumbar and thoracic spines confounds sit-and-reach test results (Worrell & Perrin, 1992). The sit-and-reach test also does not allow isolations of the hamstring muscles (Coole & Gieck, 1987).

The subjects perform the straight leg raise test in a supine position. The leg is passively flexed with the knee in full extension until the leg encounters resistance. Pelvic rotation and foot position confound the straight leg raise test (Worrell & Perrin, 1992). Coole and Gieck (1987) recommend the active knee extension test because it reduces involvement of pelvic rotation and allows unilateral testing.

Lysens et al. (1984) examined the predictability of sports injuries. The authors classified risk factors into two categories: (a) extrinsic factors related to the sport, and (b) intrinsic factors related to both the individual's physical and psychological factors. The authors considered muscle tightness as an intrinsic factor in their discussion of studies that relate tightness to muscle strain. However, in their research study of 138 physical education students who trained under the same conditions and were exposed to similar extrinsic risk factors, there was no statistical evidence to associate muscle tightness with strain.

Several other studies examined hamstring muscle flexibility. Burkett (1970) collected data to provide information on the possible causes of hamstring injuries. He examined a sample of track athletes after injury: an experimental group of 12 runners and a control group of 18 runners. Burkett applied the data collected from this sample to another group composed of 32 football players. In his second study, he examined hamstring flexibility in football players using the Well's sit-and-reach test. Using the information gained initially from the track athletes, Burkett selected candidates for potential hamstring strain. The author based selection on (a) strength imbalances, (b) flexion/extension ratios, (c) bilateral muscle strength, (d) power, and (e) sit-and-reach scores. Burkett found no significant relationship between the results of the flexibility exam and hamstring muscle strain.

Liemohn (1978) examined the factor of unilateral hip joint flexibility in relation to hamstring strain in 27 members of a university track and field team. Subjects participated in (a) sprinting, (b) long and high jumping, and (c) pole vaulting. Seven of the 27 subjects sustained hamstring injuries, five of which were moderate and the other two were mild. The researcher examined hip joint flexibility using a goniometer. Results indicated that the injured men tended to be less flexible at the hip than the noninjured. However, the data did not show the least flexible limb to be the limb usually injured.

In 1988, Stephens and Reid conducted a study that investigated the relationship between flexibility and strength to hamstring strains in sprinting positions of rugby football players. The author divided the 26 rugby football players in the experiment into a control group of 19 and an experimental group of 7. The researchers examined flexibility using still photography and the Well's sit-and-reach test. Results of their study indicated no differences in flexibility between injured and noninjured football players in sprinting positions.

Jonhagen, Nemeth, and Eriksson (1994) measured tightness by examining hamstring flexibility of 11 hamstring injured sprinters and a control group of 9 noninjured sprinters. In this study, the authors assessed flexibility using the straight-leg raise test and analyzed the data by a Student's *t*-test and analysis of variance (ANOVA). Results indicated a significant difference in hip joint range of motion (ROM) between injured sprinters and uninjured sprinters. The hip joint ROM for the injured sprinters was 67.2°; for the control group it was 74.1°. In this study, sprinters who sustained hamstring injuries had tighter hamstrings than sprinters in the control group. The study raises the question of whether injury cause tight hamstring muscles or tight hamstring muscles are a cause of injury.

Worrell et al. (1991) sought to determine the relationship of hamstring flexibility to hamstring muscle injury. Subjects included 32 highly skilled male athletes divided into two groups. Group 1 was the hamstring injured group. Athletes in Group 1 had experienced sudden or delayed muscle pain in the posterior thigh that prevented participation for at least 7 days. Subjects in Group 2 were free from any history of hamstring muscle injury. This study excluded subjects with current injuries. All the subjects participated either in (a) football, (b) track, (c) soccer, or (d) lacrosse. The authors determined hamstring flexibility through the Passive Knee Extension Test. In this test, the researcher passively extends the knee while the subject maintains the hip at 90° flexion. The end of flexibility is the point in the knee's range of motion where it encounters resistance. The hamstring injured subjects were significantly less flexible in both extremities when compared to subjects in the noninjured group. Results also indicated that the injured extremity was significantly less flexible than the noninjured extremity of subjects in the hamstring injured group. The legs of subjects in Group 1 were less flexible than the legs of subjects in Group 2. According to the authors, hamstring muscle injuries appeared to have resulted in additional loss of hamstring flexibility.

Wang, Whitney, Burdett, and Janosky (1993) examined lower extremity muscular flexibility in long-distance runners. The authors proposed that a number of factors contribute to flexibility, including (a) gender, (b) age, (c) muscle size, and (d) warmup. The purpose of this study was to determine the muscle flexibility of the (a) hamstrings, (b) rectus femoris, (c) iliopsoas, (d) gastrocnemius, and (e) soleus muscle in long-distance runners as compared to a nonrunning group. Forty subjects were divided into two groups: one group of 20 runners and one group of 20 nonrunners, each having 10 males and 10 females. Researchers used a modified straight-leg-raise test, passive hip flexion with the knee extended, to determine hamstring muscle tightness. They measured flexibility, the point where the onset of posterior pelvic tilt originates, using a goniometer. Results of this study showed that runners have tighter hamstrings than nonrunners. The author concluded that hamstring tightness is due to long-term use in long-distance running. The authors stated three factors which are associated in hamstring muscle length: running, gender, and leg dominance.

Ekstrand and Gillquist (1982) examined muscle tightness to determine its frequency and its contribution to injuries of soccer players. The purpose of the research was to investigate the past injuries sustained by 180 soccer players and to analyze their persisting symptoms, as well as the incidence of muscle tightness in the lower extremities. Eighty-six nonsoccer players were placed into a control group. Subjects were interviewed and examined for five movements of the lower extremity: (a) hip flexion with the knee straight, (b) hip extension, (c) hip abduction, (d) knee flexion lying prone, and (e) ankle dorsi flexion with the knee straight. Researchers measured these movements using a goniometer. Muscular tightness existed when the range of movement was below normal, minus two standard deviations of the same range for the reference groups.

Results of this study found no difference between right and left sides in either group. When examining the movement of hip flexion, the soccer players were more flexible than the control group but were tighter in other movements. Strains occurred in 31% of the players with muscle tightness but in only 18% of the players with normal flexibility (Ekstrand & Gillquist, 1982). Strains of the hamstrings were more common in the dominant leg.

In 1983, Ekstrand and Gillquist examined injuries in soccer players to assess etiological factors responsible for soccer injuries in order to suggest methods of injury prevention. The authors examined 180 soccer players for muscle tightness. The authors found no difference in range of motion between players with hamstring strains and players with no hamstring strains. The soccer players were less flexible than the nonplayers and their muscle tightness correlated to strains of the adductors.

Mangine, Noyes, Mullen, and Barber (1990) sought to establish five tests that could determine the physiological profile of the elite soccer players. This five-year study examined 34 noninjured soccer players. The five tests sought included (a) a flexibility evaluation, (b) a knee ligament test, (c) a Wingate

Performance Test, (d) an isokinetic strength test, and (e) body composition. The authors categorized flexibility measures as (a) normal, (b) borderline, or (c) tight.

Results of the study by Mangine et al. (1990) indicated normal ROM for the hamstrings. The authors considered only 17% of the hamstring muscles tested tight, or having 70° to 80° of hip flexion. Flexibility was compared to incidence of hamstring muscle strain in the tested group. Eight players had reported a history of hamstring strain, of which (a) two had normal flexibility, (b) four were borderline, and (c) two were tight. The author concluded there is no correlation of flexibility of the hamstrings to injury.

Flexibility and posture are among the factors reported to be associated with hamstring strains. Postural defects may predispose athletes to certain injuries. Hennessy and Watson (1993) examined flexibility and posture in relation to hamstring injury. The researchers examined the relationship between hamstring flexibility and history of injury. Posture and flexibility were assessed in 34 athletes from (a) rugby, (b) hurling, and (c) Gaelic football. The authors divided subjects into an injured group of 18 and a control group of 16. Hamstring flexibility was measured using a custom device which employed a large protractor and a meter ruler. Researchers also assessed posture using the New York Posture Rating Chart. Flexibility results showed no difference between groups for either (a) left or right legs, (b) injured and noninjured legs within the injured group, and (c) the mean flexibility of both left and right legs. The range of motion of subjects in this study was similar to the range reported in other athletes (81.5°). The range of motion for hip flexion was 77.1° for noninjured and 77.8° for injured athletes.

Rudy (1986) examined the relationship between hamstring muscle injuries and contractile characteristics of flexibility and fatigability in sprinters. The author assessed flexibility using the active straight-leg raise test and the sit-and-reach test. This study revealed very low incidence of hamstring injuries in sprinters. Rudy found no relationship between the results of the sit-and-reach and the active straight-leg raise tests and hamstring muscle injuries.

Flexibility Summary

Research has shown that the lack of flexibility contributes to hamstring muscle strain (Burkett, 1970; Ekstrand & Gillquist, 1982, 1983; Hennessy & Watson, 1993; Jonhagen et al., 1994; Liemohn, 1978; Stephens & Reid, 1988; Wang et al., 1993; Worrell et al., 1991). Agre (1985) discussed the factor of insufficient flexibility and its role in hamstring muscle injury. Agre states when there is a lack of flexibility, the musculotendinous unit may be stretched beyond its ability to elongate, in the late swing phase of sprinting, and tear. He found that this is more likely to occur during sprinting when there is a greater requirement for flexibility and forces are at a maximum.

If there is a difference in flexibility between limbs or if a person lacks a certain degree of flexibility, hamstring stretching programs should be implemented to correct this problem and to reduce the chance of sustaining muscle strain. Flexibility ranges will vary between individuals; therefore, flexibility must have individual consideration.

Strength

Over the last few decades, several authors have studied muscle strain and have indicated strength to be a factor associated with hamstring muscle strain. Worrell and Perrin (1992) concluded that the stronger hamstring can absorb more force. In 1970, Burkett examined strength as a predictor of hamstring muscle strain. In his sample of football players, 32 subjects made up the control group; 5 subjects with four new strains and one old strain made up the experimental group. Of the 37 total subjects, Burkett predicted six players to be candidates for hamstring muscle strain. Within 3 weeks after testing, four of the six candidates strained the hamstring muscle. Results of the cable tension test determined a 10% deficit to be a critical value when looking at bilateral strength imbalances. Six of the 37 football players tested exceeded the 10% strength deficit. Through bilateral strength testing, Burkett predicted which limb would sustain the strain, and concluded that the reduction of the strength imbalance is useful in preventing hamstring strains.

Work (1975) tested the 10% muscle strength imbalance theory. Work used a cable tensiometer to measure isometric hamstring muscle strength at the angle of 135° knee flexion in 30 rugby football players. Of the subjects examined, 13 had a muscle strength imbalance greater than the suggested 10%. Only 1 (with an imbalance of 15.82%) of the 13 subjects with a greater than 10% muscle strength imbalance suffered hamstring injury. In contradiction to Burkett's 1970 conclusion, Work concluded that an imbalance of greater than 10% was not a causative factor of hamstring muscle injuries. Work states that there may be a need for a greater imbalance, perhaps 20% to 30%, before muscle strength imbalance can be classified as a causative factor. Factors other than strength were not examined. Work suggests that future research should examine reciprocal inhibition theories.

Liemohn (1978) examined the factor of strength in relation to hamstring muscle strain. The author tested strength isometrically using a cable tensiometer at flexion angles of 115° and 165°. The author selected the two joint angles for measure, hypothesizing that as the joint angle is increased, the function of the hamstrings is changed. Results of this study revealed strength imbalances in the group of injured sprinters and greater right flexor strength in the noninjured.

Methods and devices for strength assessment later began to appear in the research, including the isokinetic dynamometer. An isokinetic dynamometer is a device that allows objective measurement of isokinetic strength, power, and power/endurance (Heiser, Weber, Sullivan, Clare, & Jacobs, 1984). Isokinetics were first introduced in 1967 and later became accepted as valuable for increasing (a) strength, (b) power, and (c) power/endurance. Isokinetics, used in much of the current research, allows detection and correction of muscle imbalances as well as safe exercise.

Gilliam, Sady, Freedson, and Villanacci (1979) examined isokinetic torque levels for flexion and extension in 115 high school football players ranging in age from 15 to 17 years. Torque levels, measured using an isokinetic dynamometer at speeds of 30°/sec and 180°/sec, revealed the greatest relationship to torque output. The torques differed across all age groups. In addition, results showed that torque differences diminish as the speed of movement increases. The authors concluded that high school athletes' torques depend on body weight.

In 1983, Ekstrand and Gillquist examined factors responsible for soccer injuries to suggest methods of injury prevention. An examination of hamstring and quadriceps muscle strength included testing at various isokinetic speeds (30°/sec and 180°/sec) and an isometric angle (60°) in 180 soccer players. The authors were unable to find strength imbalances in the hamstrings.

Heiser et al. (1984) reviewed the number of hamstring strains in a 5-year period before the use of the isokinetic dynamometer. Their study was retrospective and examined hamstring injuries pre-isokinetics and with isokinetics. Group I was made up of subjects evaluated during a 4-year period for hamstring muscle strains. In 534 athletes, there was a total of 41 first-degree hamstring strains and a total of 13 hamstring injury recurrences. Subjects in Group I received prophylactic conditioning for rehabilitation. Group II consisted of subjects evaluated from 1978 through 1982 who received (a) stretching, (b) weight training/running, and (c) testing on an isokinetic dynamometer. Athletes who displayed a greater than 10% deficit and less than 0.50 hamstring/quadriceps (H/Q) ratio were considered likely to strain, and were placed on isokinetic strengthening rehabilitation. Subjects in Group II returned when strength deficits were less than 5% or when there was a greater than 0.55 H/Q ratio. Among the 564 subjects in Group II, there was a total of six strains with no recurrences. Results of this study indicate a reduction in the number of hamstring muscle strains and no recurrences in those subjects who sustained strains prior to isokinetic testing. The authors concluded that retrospective analysis is not representative of the incidence of hamstring strains in football. The reduction of strains in Group II may have been the results of increased emphasis on stretching and strength training.

In a study of 26 rugby football players, Stephens and Reid (1988) examined isokinetic strength of the hamstrings at 60°/sec to determine if a strength relationship to hamstring strain exists in the sprinting position. The researchers used an isokinetic dynamometer to evaluate isokinetic hamstring muscle strength. Results of their study do not support a 10% strength imbalance as a predictor of hamstring strain. The noninjured subjects had a 10.6% bilateral strength difference and the injured subject had a 12.15% difference. There was no difference in strength between the injured and noninjured football players in sprinting positions.

Mangine et al. (1990), in their study of the profile of elite soccer players, examined muscle strength using an isokinetic dynamometer at speeds 60°/sec and 450°/sec. Their results indicate that there are no strength differences and that data for all subjects were within 10%, supporting the results found by Stephens and Reid (1988).

Worrell et al. (1991), in a study of flexibility, examined muscle strength in 32 skilled athletes. The author divided subjects into two groups: (a) one with a history of hamstring injury and (b) one without such history. Researchers sought to determine if bilateral differences existed in several quadriceps and hamstring strength indices and reciprocal muscle group ratios. An isokinetic dynamometer measured peak torque in the subjects. The authors measured eccentric and concentric strengths at 60°/sec and 180°/sec, and analyzed the data through analyses of variances (ANOVA) tests. The data shows the eccentric torque is greater than the concentric torque at an isokinetic speed of 180°/sec. There is no significant difference in torque between eccentric and concentric muscle contraction at 60°/sec. Results indicate no significant strength differences in any of the strength measures between the two groups.

Jonhagen et al. (1994) examined concentric and eccentric hamstring muscle strength. This study compared 11 sprinters with recent hamstring injuries to 9 uninjured sprinters. Researchers measured eccentric and concentric muscle torque at different angular velocities and assessed muscle strength isokinetically for eccentric velocity torque. The authors included only one leg of each of the injured and noninjured subjects in the statistical analysis. The uninjured sprinters showed higher torque values at 30°/sec during concentric contraction of the hamstrings and quadriceps. The torques at all three eccentric speeds were greater in the uninjured sprinters. The injured group had a relatively higher torque at high angular velocities than the uninjured group. Sprinters who suffered from hamstring injuries were weaker in eccentric contraction of the hamstrings at all the velocities.

In Rudy's (1986) study of track sprinters, the author assessed strength on an isokinetic dynamometer. Subjects were tested at speeds of (a) 60°/sec, (b) 180°/sec, and (c) 300°/sec, as well as isometrically at 45°. Results indicated that 7 of the 24 athletes had a strength imbalance over 10%. Rudy made no strength conclusions because hamstring muscle strength and its relation to injury was not a focus in this study.

Yamamoto (1993) examined the relationship between hamstring strain and leg muscle strength. The author used bilateral isometric extension and flexion maximum voluntary contraction (MVC) of the knee and hip to assess strength of 64 collegiate track and field athletes. A cable tensiometer measured the strength of six performance variables: (a) knee extension, (b) knee flexion, (c) forward leg pull, (d) backward leg pull, (e) hip extension, and (f) hip flexion. Yamamoto assessed hamstring muscle strength (knee flexion) at an isometric knee flexion angle of 165° with the subject in a prone position. Of the 64 subjects (128 legs), 26 subjects or 24.2% had suffered from hamstring strains. The author then divided the subjects into an injured and a noninjured group and found no significant difference of the MVC of the knee flexor between the injured and uninjured groups.

Yamamoto (1993) included a strength imbalance index in his study expressed as a percentage, equal to the MVC of the stronger minus the weaker divided by the MVC of the stronger times 100. Results of the bilateral imbalance index showed higher indexes of hip flexion and knee extension. The index for hip flexion in the strain group was 13.67 while the index in the nonstrain group was 9.22. The strength index for knee extension was 13.25 in the strain group and 8.42 in the nonstrain group. These results show that imbalances in knee extension and hip flexion are strength imbalances associated with hamstring muscle strain. The author examined the ratio of flexion strength to body weight. The knee flexion MVC per body weight was 5% lower in the injured group. The author found that this MVC per body weight is a factor associated with hamstring muscle strain. Muscle activity associated with running increases as speed increases. The hip flexors show the highest increase of muscle activity with the increase of speed. The hip flexors, along with the knee extensors, play a major role in propelling the body forward during sprinting. Yamamoto concluded bilateral differences to be dangerous factors, especially in high-speed movements.

Several studies have examined the strength characteristics of the hamstring muscles and their relation to various factors. Parker, Holt, Bauman, Drayna, and Ruhling (1982) assessed the status of the quadriceps and hamstrings in relation to body weight in high school football players. The authors performed isokinetic evaluations on 84 male athletes and found bilateral hamstring torque differences of 9.3%. Parker et al. used linear regression to analyze hamstrings and quadriceps torques and torque to body weight of both right and left extremities. Results of this study suggest that the use of body weight as a clinical barometer of normal quadriceps and hamstring torque is a method of considerable error and should be used with caution.

Rankin and Thompson (1983) made an attempt to establish normative data for quadriceps and hamstring strength in all incoming athletes (N=1,519) at Michigan State University during a 2-year period. The researchers used an isokinetic dynamometer to test hamstring muscle strength at 60°/sec, 180°/sec, and 300°/sec. Hamstring torque to body weight ratio (T/BW) at 60°/sec was examined with the results revealing a ratio of 0.597. The authors noted significant difference in T/BW ratios between males and females. Also noted was a significant difference in torque to body weight ratios between sports.

In 1983, Morris, Lussier, Bell, and Dooley used an isokinetic dynamometer to measure the strength of knee flexors and extensors in 12 middle-distance and long-distance runners. Subjects were tested isometrically at 50° and isokinetically at (a) 30°/sec, (b) 60°/sec, (c) 180°/sec, (d) 240°/sec, and (e) 300°/sec. The authors also examined the torque to body weight (T/BW) ratio of the subjects. Results showed that as the speed of the contraction increased, there was a gradual decrease in the T/BW ratio of the runners. Morris et al. recognized bilateral differences at 180°/sec and 300°/sec to be 11% and 7%, respectively. The authors stated that some professionals suggest 5% as a limit for bilateral differences. There was a decrease in torque (41%) as the angular velocity increased, most likely due to the increase in the percentage of fast-twitch muscle fiber activity.

Read and Bellamy (1990), in comparing hamstring/quadriceps isokinetic strength ratios and power, examined hamstring muscle strength. Eleven elite track athletes, 11 squash players, and 11 top-ranked British tennis players were tested on an isokinetic dynamometer. Researchers tested subjects at speeds of (a) 90°/sec, (b) 180°/sec, (c) 240°/sec, and (d) 30 repetitions at 300°/sec. The analysis of variance (ANOVA) showed torque ratios to be significantly different between individuals, especially at higher speeds. However, the authors noted no significant strength differences between groups. Differences in preferred and nonpreferred legs correlated to results in another study by Stafford and Grana (1984). The fact that power was the same between legs, but the ratios were different, indicates that the hamstrings contribute proportionately more power at high speeds (Read & Bellamy).

Stafford and Grana (1984), in their study of hamstring/quadriceps power ratios in college football players with no current knee problems, examined hamstring muscle strength using an isokinetic dynamometer. They tested subjects at speeds of (a) 90°/sec, (b) 180°/sec, and (c) 300°/sec. Results showed peak torque of the hamstrings to drop as the velocity increased. There was no mention of bilateral differences in peak torque.

Strength Summary

The ability of connective tissue and muscle tissue to absorb force is directly proportional to both passive and active components. When considering the strength factors, imbalances were examined, with the conclusion that the more imbalance the more an athlete is prone to injury. What determines a significant discrepancy in strength depends on (a) the anatomical region, (b) the sport, and (c) the participant's, size, age, and gender (Grace, 1985). Through mechanically evaluating the hamstrings, (a) the basic degree of muscle bilateral strength, (b) degree of weakness, and (c) degree of imbalance can be determined (O'Neil, 1976).

Agre (1985) described the factor of muscle strength in relation to hamstring muscle injury. He postulated that if the strength of the hamstring is poor, the force of contraction may be insufficient to counter the force of knee extension during swing phase or to provide torque for hip extension during the stance phase, resulting in overstretch injury.

Many studies indicate a relationship between hamstring muscle strength and muscle strain (Burkett, 1970; Ekstrand & Gillquist, 1983; Gilliam et al., 1979; Heiser et al., 1994; Jonhagen et al., 1993; Liemohn, 1978; Mangine et al., 1990; Rudy, 1986; Work, 1975; Worrell et al., 1991; Yamamoto, 1994). Major strength imbalances are not common in the athletic population. Athletic trainers have used isokinetic evaluations to assess hamstring muscle strength and to detect strength imbalances. Strength imbalances may place excessive stresses on muscular structures that could lead to failure. Research has demonstrated that subjects with greater than 10% hamstring muscle strength imbalance are more likely to suffer hamstring muscle strain. Strength is a factor in which imbalances, if detected, can be corrected or reduced through strength training to lessen deficits and the chances of muscle strain.

<u>Hamstring/Quadriceps Ratio</u>

Burkett (1970) examined the hamstring to quadriceps (H/Q) torque ratio and showed it to be a factor associated with hamstring muscle strain. The researcher selected football players determined to be future candidates for hamstring strain as the experimental group. The H/Q ratios in the experimental group were 47.7% compared to 50.53% in the control group of other football players. In his examination of track athletes, the H/Q ratios were higher, with the experimental group having a ratio of 65.16% and the control group having a ratio of 65.55%. The lower H/Q ratio seen in the football experimental group was determined to be a factor associated with hamstring muscle strain. Of the six members in this experimental group, four sustained hamstring strain 3 weeks after testing.

In 1972, Christensen and Wiseman examined strength, the common variable in hamstring strain. This study of nine track athletes, the researchers examined flexibility and isometric H/Q strength. Although flexibility was examined, there was no correlation found. All subjects had a flexibility range of at least 75° hip flexion. Researchers examined strength using a cable tensiometer which measured strength at knee joint angles of 120° and 150° and determined the critical score using a *t*-test with 8° of freedom. Athletes with a ratio below the mean at a .01 significance level at either joint angle for each limb were classified as being subject to hamstring muscle strain. Of the nine subjects, five fell below the critical score for H/Q muscle strength for either leg at both joint angles. Of the five subjects who scored below the critical value, two sustained left hamstring muscle strains. At the angle of 120°, the right hamstring had a mean ratio of 0.48, and the left a mean ratio of 0.45. At an angle of 150°, the right leg had a mean ratio of 1.10, and the left a mean ratio of 0.94. Results indicated that the H/Q ratios vary with joint angle and that the subjects who scored above the critical value incurred hamstring strain.

In examining factors related to hamstring strain among track athletes, Liemohn (1978) measured quadriceps and hamstring strength using a cable-tensiometer. The hamstring/quadriceps ratios in the injured sprinters were lower than in the noninjured, indicating that the injured sprinters' hamstrings were weaker than their quadriceps strength. The author stated that characteristics of the athletic events may allow a more specific identification of hamstring injury.

Stephens and Reid (1988) also examined H/Q ratios in their study of rugby football players. They obtained H/Q ratios of 0.40 in the noninjured group and 0.48 in the injured group. Their results do not support the belief that a ratio of 0.60 to 0.70 would be appropriate for a ratio of hamstrings to quadriceps strength.

Yamamoto (1993) examined flexion/extension ratios in an attempt to determine the relationship between hamstring strains and leg muscle strength. Subjects included 64 male athletes grouped in either a control group (uninjured) or an experimental group (injured). The researcher measured torques isometrically at a joint angle of 165° with the subject prone. H/Q ratios in the strained legs were 0.46, and in the nonstrained legs, 0.51. Results in this study indicated the ratios of the injured group were generally lower than those of the uninjured group.

Several studies examined the hamstring to quadriceps ratio to determine normative values and other characteristics. Work, in his 1975 study of rugby football players, examined the hamstring/quadriceps ratio while testing the 10% imbalance theory. Of the 30 subjects, the author assessed H/Q in 22 subjects. The author omitted eight subjects in calculating the mean because the flexor value exceeded the extensor value and this could have given misleading overall results. Results of this study produced a mean H/Q ratio of 69.23. The author concluded that there is greater flexor development due to the specific demands of the rugby football.

Gilliam et al. (1979) examined isokinetic H/Q ratios in high school football players. At 30°/sec, the H/Q ratio was 0.60, and at 180°/sec, the H/Q ratio was 0.77. The H/Q ratios were greater for the linemen than for players in other positions.

Davies et al. (1981) examined isokinetic characteristics of professional football players, in order to establish normative relationships between quadriceps (Q) and hamstring (H) muscle groups relative to body weight (WT). There were 91 subjects tested isokinetically at (a) 45°/sec, (b) 180°/sec, (c) 240°/sec, and (d) 300°/sec. Hamstring to quadriceps (H/Q) ratios, quadriceps to body weight (Q/WT) ratios, and hamstrings to body weight (H/WT) ratios were determined for each subject and subjects were grouped by playing position.

Results indicated variability of ratios between player positions (Davies et al., 1981). At the isokinetic speed of 45°/sec, the H/Q ratio had a low of 51.0 (offensive linemen) and a high of 64.9 (defensive linemen) with an overall H/Q ratio of 60.9. The Q/WT ratio had a low of 0.94 (offensive linemen), a high of 1.13 (defensive linemen), with an overall ratio of the Q/WT being 1.07, while the H/WT ratio had a low of 0.57 (offensive linemen), a high of 0.74 (offensive backs), and an overall ratio of 0.65. At the higher isokinetic velocity of 300°/sec, H/Q ratios resulted in a low of 75.2 (offensive backs) with an overall ratio of 80.4. The low for the Q/WT ratio was 0.30 seen in the offensive linemen with an overall ratio of 0.35. The H/WT ratio had a low of 0.25 for the defensive linemen with an overall H/WT ratio of 0.30. This study gave objective values for quadriceps and hamstring torques in professional football players at various isokinetic speeds. The authors state that if the H/Q ratio is about 60%, then the value of the quadriceps becomes critical, for it is the denominator in the ratio.

Rankin and Thompson (1983) examined H/Q ratio in all incoming university athletes, male and female in all sports, to establish normative data. Selected results of the H/Q ratio at 60°/sec were (a) 0.63, (b) 0.63, (c) 0.69, and (d) 0.64 for (a) linebackers, (b) backs, (c) lineman, and (d) track-distance runners, respectively. At 300°/sec, the hamstring/quadriceps ratio was 0.88 in the track distance runners. Results of the normative data support the results of the study by Gilliam et al. (1979), in that hamstring/quadriceps ratios vary by sport and by position.

Morris, Lussier, Bell, and Dooley (1983) examined hamstring/quadriceps ratios in runners. The H/Q ratio was lowest at speeds of high torque. Results at speeds of (a) 30°/sec, (b) 60°/sec, (c) 180°/sec, (d) 240°/sec, and (e) 300°/sec were (a) 0.63, (b) 0.65, (c) 0.76, (d) 0.83, and (e) 0.87, respectively. The results of this study indicate that the H/Q ratio is not a fixed value. The authors considered strength event-specific; that is, specific to the demands put on the athletes by the sport in which they compete.

Stafford and Grana (1984) examined hamstring/quadriceps ratios in 60 varsity college football players. This study shows that the optimal hamstring/quadriceps ratios vary at different speeds, and hamstring/quadriceps ratios increase as test speeds increase. The purpose of this study was to calculate hamstring/quadriceps ratios at three functional speeds: (a) 90°/sec, (b) 180°/sec, and (c) 300°/sec on selected college football players. Subjects were tested on an isokinetic dynamometer and were free of any current knee problems. Results of this study showed that when compared bilaterally, the hamstrings, unlike the quadriceps, show virtually no difference in peak torque. Ratios approaches unity in both dominant and nondominant knees as speeds increases. The dominant knee possesses a significantly lower hamstring/quadriceps ratio than the nondominant knee at all speeds. The flexors, whose power ratios increase as speeds increase, play a greater role in muscular balance at high speeds. It was concluded that at the slower speeds, the quadriceps are more dominant as seen in lower ratios.

This study (Stafford & Grana, 1984) demonstrated the rise in hamstring/quadriceps ratios as limb velocity increases. Means in this study for hamstring/quadriceps ratios were (a) 67% at 90°/sec, (b) 73% at 180°/sec, and (c) 82% at 300°/sec for the dominant leg, with the nondominant leg being slightly higher and significantly different. The authors concluded that as velocity increases, torque decreases, and the quadriceps have greater torque than the hamstring muscles at all speeds. The authors recommend that bilateral hamstring/quadriceps ratios be compared at each speed when comparing the strengths. While the bilateral torques are within the normal limits of 90%, the ratios may not necessarily be within normal limits. In addition, the flexor/extensor ratio may be a more sensitive indicator of functional ability.

Read and Bellamy (1990), in their study of elite squash, tennis, and track athletes, examined hamstring to quadriceps strength ratio. At an isokinetic speed of 90°/sec, the average H/Q ratio for the preferred leg was (a) 0.74 for squash, (b) 0.74 for tennis, and (c) 0.77 for track athletes. The ratios of the preferred leg at 180°/sec were (a) 0.84 for squash, (b) 0.80 for tennis, and (c) 0.92 for track athletes. At a speed of 240°/sec, ratios of (a) 0.88 for squash, (b) 0.87 for tennis, and (c) 0.92 for track athletes were obtained for the preferred leg.

At the final speed of 300°/sec, subjects produced ratios of (a) 0.97 for squash, (b) 0.89 for tennis, and (c) 1.08 for track in the preferred leg. Differences between leg ratios seen at the lower speeds may indicate clinical abnormality, whereas tests at the higher functional speeds are more influenced by gravity. This may indicate natural differences between the preferred and nonpreferred leg of a subject. The authors stated that the test results were not corrected for the effect of gravity, which would explain the significant natural differences the researchers noticed between legs and the wide range of individual values. They suggest caution in equalizing both sides of the body. They also suggest that training methods may influence the hamstring to quadriceps ratio between contralateral legs.

In 1990, Mangine et al. examined the hamstring to quadriceps ratio. This study included five tests to establish a physiological profile of elite soccer players. Ratios for the hamstrings to quadriceps at 60°/sec were 0.56 for the right leg and 0.57 for the left leg. At 450°/sec, the H/Q ratio was 0.67 for the right leg and 0.70 for the left leg. Researchers noted no significant difference in the H/Q ratios.

Hamstring/Quadriceps Ratio Summary

Several studies have examined the relationship between the H/Q ratio and hamstring muscle strain (Burkett, 1970; Christensen & Wiseman, 1972; Liemohn, 1978; Stephens & Reid, 1988; Yamamoto, 1993). Studies associated a low hamstring/quadriceps ratio to hamstring muscle strain. Health practitioners must consider this ratio in their evaluations, for it may vary with muscle testing techniques. It appears that a normal range for this ratio is from 0.60 to 0.70. Studies show this ratio to vary with testing speed. At higher angular velocities, the ratio of the hamstrings to quadriceps will increase. Studies show that ratios vary by sport; however, the difference is not great. By determining the hamstring/quadriceps ratio, major strength imbalances between these groups of muscles can be reduced, which may lessen the chance of hamstring muscle strain.

<u>Eccentric Muscle Contraction/Muscle Fiber Composition</u>

Some literature associates eccentric muscle contraction and muscle fiber composition with hamstring muscle strain. Jonhagen et al. (1994), in their study of eccentric muscle work, found that eccentric muscle contraction is more efficient and requires less oxygen than concentric muscle contraction. Furthermore, tension can become much higher in eccentric contraction with the possibility of developing high intrinsic force within the muscle. In a pilot study, these researchers found that hamstring strain was more common in faster sprinters; thus, faster sprinters need greater strength, both to be able to run fast and to avoid injury. If eccentric function is poor with the high levels of Type II muscle fibers, sprinters have a higher risk of developing muscle injury.

In addition to eccentric function, the role of the fiber makeup of the hamstring muscle group in intrinsic force production is also important. Sprinters have a higher distribution of Type II muscle fibers, and the hamstrings have a greater concentration of Type II muscle fibers than the quadriceps (Jonhagen et al., 1994), which was supported in a study by Garrett, Califf, and Bassett in 1984.

Garrett et al. (1984) examined the histochemical fiber-type composition of the human hamstring muscle to determine the etiology of these muscle injuries. Histochemical analysis differentiates the types of muscle fibers. The researchers took muscle samples at the time of autopsy from 10 subjects, male and female. None of the subjects had neuromuscular disorders that were associated with an abnormal fiber type distribution. Garrett et al. took distal and proximal samples from the (a) quadriceps, (b) adductors, (c) semitendinosus, (d) semimembranosus, and (e) biceps femoris long head. The ATPase histochemical reaction was used to determine the fiber type. Results indicated that the hamstring muscles have a higher percentage of Type II muscle fibers than the quadriceps. This reflects the functional requirement of the hamstring muscles, as being one of fast activity. The Type II muscle fibers seen in the hamstring muscles are fast-contracting, well endowed for anaerobic metabolism, and involved in muscle contractions of greater intensity.

Eccentric Muscle Contraction/Muscle Fiber Composition Summary

Although research is not conclusive, eccentric muscle contraction and the fiber composition of the hamstring muscles are believed to predispose athletes to hamstring muscle strain. Stanton and Purdam (1989) presented an article that examined hamstring injuries in sprinters and the role of eccentric exercise. This article focused on (a) poor conditioning, (b) overlooked musculotendinous insufficiencies, and (c) eccentric muscle activity. The authors found that when limb velocity increased, the concentric and eccentric forces produced increased dramatically. Eccentric activity related to hamstring injuries occur in the late swing phase of the gait as the foot hits the ground. Eccentric muscle action can produce a greater force than concentric muscle action. As the velocity of the muscle contraction increases, the maximum eccentric force producible increases, and the maximum concentric force producible decreases. With higher tension produced for the same amount of motor activity, eccentric contractions place greater stress on the series elastic component (SEC) which leads to pathological forces within the SEC.

Eccentric muscle contraction followed by concentric muscle contraction will increase the concentric forces due to energy storage and recovery of elastic energy, coupled with reflex potential through muscle spindle discharge. This is seen in participants in sports with high speeds of movement (Stanton & Purdam, 1989). The eccentric function of the hamstring muscle during ambulation, coupled with the hamstring muscle's ability to produce high forces within, due to its muscle fiber makeup, contributes to hamstring muscle strain if function is poor.

Chapter Summary

There are several factors that predispose an athlete to hamstring muscle strain (see Table 1). Those factors include the flexibility of the hamstring muscle

Table 1

Factors that Predispose Athletes to Hamstring Muscle Strain

1. Flexibility
2. Strength
3. Hamstring/Quadriceps Ratio
4. Eccentric Muscle Contraction / Muscle Fiber Composition

group which may contribute to strain. A second factor associated is the strength of the hamstring muscles. Strength imbalances may be an indicator that the muscle may be predisposed to injury. The H/Q ratio can indicate the hamstring muscle predisposition to strain. A low ratio may lead to muscle strain with activity, however, this ratio varies with testing speeds. Another factor that predispose athletes to hamstring muscle strain include eccentric muscle contraction and the muscle fiber composition. The eccentric activity that occurs in the late swing phase of the gait combined with the intrinsic forces produced by the Type II muscle fibers makes this a factor that can lead to hamstring muscle strain.

Chapter IV

REVIEW OF LITERATURE: OTHER FACTORS LEADING TO HAMSTRING MUSCLE STRAIN

This chapter details additional factors that may predispose an athlete to hamstring muscle strain. The factors mentioned in this chapter are associated with the factors presented in Chapter III. The following factors were subject to limited research in the literature, meaning, these factors makeup a small amount of the literature involving the factors that predispose an athlete to hamstring muscle strain (See Table 2).

Table 2

Associated Factors Leading to Hamstring Muscle Strain

1. Fatigue
2. Warmup
3. Poor Running Style and Early Return to Activity
4. Posture
5. Anatomical
6. Psychological

Fatigue

Hamstring muscle fatigue is a factor believed to be associated with hamstring muscle strain. Fatigue was examined by Rudy (1986) in a study that determined the relationship between injuries and contractile characteristics (flexibility and fatigability) in sprinters. The author tested 24 track sprinters for fatigue on an isokinetic dynamometer. Rudy defined fatigue as the point at which torque drops below 50% of the maximum torque before the end of a 30-second period. Eleven of the 24 subjects fatigued, indicating a significant relationship existed between contractile characteristics and injury rate. Of the 11 subjects that fatigued, 5 sustained injury. The author concluded that if the subjects did not fatigue, they would not sustain injury, and that fatigability was significantly related to hamstring muscle strain. Rudy noted that this study revealed a very low incidence of injuries sustained overall.

In a study of factors responsible for injuries in which strains occurred to the lower extremities, injuries occurred at the beginning of practice and in games with teams which did not utilize warmup or stretching activities (Ekstrand & Gillquist, 1983). Research on fatigue is limited; however, several authors suggest muscle fatigue as a factor associated with hamstring muscle strain (Ekstrand & Gillquist; Heiser et al., 1984).

Agre (1985) stated that dys-synergia, a factor he claims is related to hamstring strain, may be the result of fatigue. Contraction may occur at the wrong time, and the muscle may exert too much force at the wrong time, creating muscle injury.

When a muscle is fatigued, there is a reduction in the muscle's ability to function. The activity of running places great demand on the hamstring muscle group. The inability of a muscle to properly function during moments of activity can lead to muscle strain. Proper training and conditioning greatly reduce the contribution of fatigue to hamstring muscle (Agre, 1985).

Hamstring muscle strains may occur in the latter part of activity due to fatigue. These strains may result due to (a) exhaustion of glycogen, (b) loss of important eclectrolytes, and (c) accumulation of lactic acid often seen in the late part of a game (Fried & Lloyd, 1992).

Warmup

Inadequate pre-exercise warmup is another factor that may predispose an athlete to hamstring muscle injury. Williford, East, Smith, and Burry (1986) completed a study in which they evaluated the effects of warming the joints by jogging and then stretching on increased joint flexibility. One reason for stretching is that it leads to a decrease in the incidence of musculotendinous injuries. The authors divided the 51 physical education students into three groups: (a) a jog then stretch group, (b) a stretch, no jog group, and (c) a control group. Afterwards they assessed flexibility of the (a) shoulders, (b) hamstrings, (c) trunk, and (d) ankle. Hamstring stretching included raising the involved leg as far as possible for 30 seconds, while keeping the opposite leg in contact with the floor for two 30-second periods. The jogging group jogged lightly but progressively for 5 minutes and then stretched. Results indicated that both jogging/stretching and stretching groups were effective in improving flexibility, but when gain scores were compared, the results varied. Results indicated flexibility can increase with static stretching, but the results do not support the premise that jogging to warm muscles will significantly increase joint angles.

Safran, Garrett, Seaber, Glisson, and Ribbeck (1988) conducted a study on rabbit models. Researchers tested the effects of muscle activation without stretch on the behavior of muscle-tendon units. They tested three muscles from each hind leg (N=60) in 10 New Zealand White rabbits. Upon tendon connection to the testing instrument, each muscle was stimulated to maximum tension. Stimulation was discontinued at the plateau of the maximal force generated.

This single contraction was defined as isometric preconditioning. The researchers pulled the muscle to failure at 10 cm/min once the electrodes were removed. The contralateral muscle was prepared in a similar fashion and pulled without the preconditioning. In four additional animals, the same procedures were followed with the addition of muscle temperature recording prior to stimulation or pulling.

The researchers studied several biomechanical parameters in preconditioned muscles. Those parameters included (a) force required to failure, (b) amount of stretch required to tear muscle, (c) site of failure, (d) length tension relationship, and (e) whether warmup provided a protective effect without applied stretch (Safran et al., 1988).

Results demonstrated that it requires more force and a greater length to tear in the isometrically preconditioned muscles (Safran et al., 1988). The authors attribute this to changes of viscoelastic properties of the intermuscular connective tissues. The isometric contractions caused by nerve stimulation may stretch the connective tissues of the muscle-tendon unit, resulting in a viscoelastic load/stress relaxation. Temperature was considered to effect this relaxation. Intramuscular temperatures were seen to rise an average of one degree Celsius within the first 10 seconds, and then to decrease thereafter.

The majority of the tension developed in the muscle is due to connective tissue elements, mostly collagen. By increasing the temperature, collagen extensibility could increase, and, therefore, muscle contraction could increase. Warmup stretches the musculotendinous units which results in an increase in length at a given load, which puts less tension on the musculotendinous junctions and reduces the incidence of strain. Muscle contraction increases muscle temperature from (a) the heat of activation, (b) from elastic energy, and (c) from the thermoelastic heat that is produced when the contraction ends. The warmup effect lasts up to one-half hour after the contraction (Safran et al., 1988).

Many authors state the importance of an adequate warmup as a factor in the prevention of muscle strains (Safran et al., 1988; Willford et al., 1986). Worrell (1994) recommends an adequate warmup period before exercise activity. Fried and Lloyd (1992) state that strains in the first few minutes usually are the result of inadequate stretching and/or warmup. In a brief review, Smith (1994) examines the warmup procedure: to stretch or not to stretch. This author states that warmer muscles are more extensible, which leads to less strain when they are stretched, as well as to increased gains in muscle flexibility. The warmup is designed to increase muscle/tendon suppleness and body temperature, stimulate blood flow to the periphery, and enhance free coordinated movement. Agre (1985) states that with insufficient warmup, the tissues are (a) cooler, (b) more viscous, and (c) tighter than after an adequate warmup. In addition, insufficient warmup might slightly impair neuromuscular coordination which could result in dsy-synergic muscle contraction. Worrell and Perrin (1992) stated that warmup prevents strain by increasing muscle elasticity and force absorption capacity.

The literature reveals that warmer muscles are less likely to strain with the demands of intense muscle activity; therefore, a proper warmup may reduce the chance of sustaining a strain of the hamstring muscle group.

Poor Running Style and Early Return to Activity

Agre (1985) believes that poor running style and early return to activity contribute to hamstring muscle strain. Poor running style is not well defined; however, some running styles may place excessive stress on the hamstring muscles. Athletes who return to sports activities before full recovery, may sustain an even more severe injury due to the lack of (a) flexibility, (b) strength, (c) endurance, or (d) coordination.

Posture

Studies have examined the contribution of posture to hamstring muscle strain. Hennessy and Watson (1993) examined the relationship between hamstring flexibility and history of strain. In addition, they looked at the relationship between history and posture. Subjects included 34 rugby, hurling, and Gaelic football players. The control group consisted of 16 subjects. The authors found no relationship between flexibility and postural components. They found each posture component to be predominately distinct. Hennessy and Watson found no difference between groups in 9 of the 10 posture components. However, there was a significant difference in lumbar lordosis between groups. There was a greater deviation in lumbar posture in the injured groups than in the control group. This difference in degree of lumbar lordosis between groups suggests that there is an association between this postural deviation and hamstring strain. The likely anatomical contributor is the iliopsoas muscle group.

In 1986, Cibulka, Rose, Delitto, and Sinacore examined the effects of manipulation of the sacroiliac joint (SI) in the treatment of hamstring muscle strains. The author evaluated 20 subjects, 18 male and 2 female, with hamstring strains as having (a) pelvic asymmetry examining posture, (b) hamstring muscle strength, and (c) flexibility of these injured subjects. The authors assessed strength using an isokinetic dynamometer at the speed of 60°/sec. The experimental group received both standard treatment and treatment through manipulative techniques for their injuries. The control group received only the standard treatment. Upon retesting the subjects' hamstring muscle strength at the test speed of 60°/sec, the experimental group noted a significant difference when comparing muscle torques. There was no difference in quadriceps strength and flexibility of the hamstrings. The authors concluded that treatment reduces the stress on injured muscles. They further determined that an anterior pelvic tilt increases the stress on the hamstrings by elongating the hamstring muscles, which contradicts the length-tension theory. In examining the injuries, hamstring muscle strains developed on the side of the anterior tilt.

Studies associated postural deviations with hamstring muscle strain. In 1982, Muckle associated anatomical factors, including lumbar spine abnormalities such as (a) disc lesion, (b) spondylolysis, or (c) facet joint athrosis with recurrent hamstring strains. Such deviations, as reported in the literature, may place stresses on the hamstring muscle group. These stresses, in addition to the stresses from activity, could lead to failure and subsequent muscle strain.

Anatomical Factors

There are several anatomical factors that predispose an athlete to hamstring muscle strain. Burkett (1976) described an anatomical factor and neuromechanism of hamstring muscle that could cause its strain. Because the hamstring muscle is a hybrid muscle, it is more susceptible to strain. The biceps femoris is a composite muscle considered hybrid because of its innervation by two separate nerves, both the tibial and peroneal nerves. During running, the hamstrings and the quadriceps oppose each other. If the strength of one is greater than the other, one must give. Usually the weaker hamstring muscle gives; therefore, balance is important. With the dual innervation, the hamstrings may be out of phase at times. This could be caused by the stimulation of the short head of the biceps femoris being greater than the stimulation of the long head of the biceps femoris which causes an imbalance in the contraction phase. The time of stimulation being different, a combination of imbalance in incorrect time of stimulation, or the change of the hamstrings from being prime movers to being stabilizers, can attribute to the hamstrings being out of phase.

Burkett (1976) further explained why the theory of strength imbalance causes strain. Through cadaver dissection, he discovered the variability of attachment of the short head of the biceps femoris, which, along with dual innervation, could be the neural mechanism for hamstring muscle strain. In addition, Burkett theorized that the extensive attachment of the short head of the biceps femoris to the linea aspera would influence hamstring strain through increasing the force applied by the short head.

With the hamstring muscles spanning two joints, it is more susceptible to strain (Burkett, 1976; Heiser et al., 1984). Being a two-jointed muscle, the hamstrings are subject to increased stretch and force production extrinsically by motion at the hip and knee (Garrett, Califf, & Bassett, 1984).

Muckle (1982) states that meniscal problems in the knee, such as (a) tears, (b) degeneration, and (c) rotatory instability, may contribute to recurrent injuries due to incomplete knee excursion that excessively loads the hamstrings. Adhesions of the lateral popliteal nerve may also contribute, and are the result of a tear in the lower muscle belly that leads to fibrosis and adhesions that could trap the nerve. Abnormal quadriceps power may produce abnormal force in the hamstrings when there is a loss of coordination due to fatigue. The author also states that enthesopathies, such as gout and ankylosing spondylitis, may contribute to hamstring muscle strain.

Yamamoto (1993) discusses the complexity of the hamstrings and their role in the movement of two joints. The hamstrings work to flex and extend the knee, coordinate movement of two main joints, and work against strong knee extensors and hip flexors. The complicated nature of the hamstrings, (a) different nerve conduction, (b) different muscle coordination, and (c) two joint movements, make this muscle group especially susceptible to injury. Therefore, it is important to have good strength balance and trained neuromuscular coordination.

Stanton and Purdam (1989) suggest that two additional factors also increase the risk of hamstring injury. First, because the hamstring crosses two joints, during the various phases of sprinting the muscle undergoes simultaneous lengthening over these two joints. This results in the hamstrings undergoing greater changes in length than muscles that cross only one joint. Second, hamstring muscles have a high proportion of "fast twitch" Type II fibers that are involved during exercises of high intensity and force production. This leads to high intrinsic force production. The increased intrinsic force production, combined with length changes over two joints, make the hamstring muscle prone to injury during sprinting and running. Garrett et al. (1984) stated that increased intrinsic force production and extrinsic muscle length changes make the hamstring muscles prone to injury during intense periods of muscular activity.

The literature identifies several anatomical factors of the hamstring muscles that may contribute or predispose athletes to hamstring muscle strain, including the dual innervation of the biceps femoris, the muscle group spanning two joints with its high percentage of Type II muscle fibers and knee pathologies (Burkett, 1976; Garrett, Califf, & Bassett, 1984; Heiser et al., 1984; Muckle, 1982; Stanton & Purdam, 1989; Yamamoto, 1993).

Psychological Factors

There are psychological factors that may contribute to hamstring muscle strain. Lysens et al. (1984) looked at the predictability of sports injuries and examined personality traits. Results indicated a relationship between (a) extroversion, (b) state/trait anxiety, and (c) injury proneness. The authors stated a need to explore more closely the individual way of life of the injury-prone subject.

Sutton (1984) suggested that the evaluation of psychological traits and personality types in relation to athletic injury should also be considered. Perhaps the aggressive athlete who is predisposed and over-exerts himself increases his chances of hamstring muscle strain.

Practical Applications for Prevention

From this study of the literature regarding factors that predispose athletes to hamstring muscle strain, there were several articles that included practical applications for prevention of hamstring muscle strains. Agre (1985) states that prevention is the best treatment for hamstring muscle strain and should include training to maintain and/or improve (a) strength, (b) flexibility, (c) endurance, (d) coordination, and (e) agility. Worrell and Perrin (1992) developed a theoretical multifactor model of hamstring muscle strain. They stated that (a) strength,

(b) flexibility, (c) warmup, and (d) fatigue are related to, rather than responsible for, hamstring muscle strain. Prevention involves pre-season screening for deficits including assessments of hamstring muscle flexibility and isokinetic strength and incorporating a stretching program. O'Neil (1976) listed three phases of prevention which include (a) muscle testing, (b) flexibility evaluation, and (c) stretching exercises. Through muscle testing, (a) the bilateral strength, (b) the degree of weakness, and (c) the degree of muscle strength imbalance can be determined. Through flexibility evaluation, results provide a permanent record on which future improvements can be evaluated. In addition, stretching exercises can maintain or improve flexibility.

Chapter Summary

There were several associated factors found in the literature that lead to hamstring muscle strain. These factors are fatigue, warmup, poor running style and early return to activity, posture, mechanical factors and psychological factors (see Table 2). From the literature a practical application for hamstring strain prevention surfaced. By understanding the factors and with an additional understanding of preventative applications, the occurrence of hamstring muscle strain can be reduced or lessen in severity.

CHAPTER V

DISCUSSION AND ANALYSIS

There is increased emphasis being placed on injury prevention in modern medicine. However, athletic trainers, physical therapists, and sports medicine practitioners are constantly seeking better methods of treating athletic-related injuries. One injury seen in athletic competition is hamstring muscle strain (Lysholm & Wiklander, 1987; Seward et al., 1993). Understanding the factors that predispose an athlete to hamstring muscle strain can promote better prevention strategies and reduce the time an athlete may not participate.

Much of the past and current research examines the factors that predispose an athlete to hamstring muscle strain as presented in Appendix A. These studies investigate the (a) single factors, (b) multiple factors, and the (c) interaction among factors related to strain. Scientific information conflicts as to the role certain factors play in contributing to hamstring muscle strain. The purpose of this study was to investigate the past and current literature to determine possible factors that are associated with and contribute to hamstring muscle strain, including the anatomy of the hamstring muscle group. In addition, this study makes recommendations for hamstring muscle strain prevention. A comprehensive computer search of the literature was conducted using available CD-ROMs that examined many databases.

Factors Leading to Hamstring Muscle Strain

There are many factors predisposing athletes to hamstring muscle strain. These factors included (a) flexibility, (b) strength, (c) eccentric muscle contraction, (d) muscle fiber composition, (e) fatigue, (f) warmup for activity,

(g) poor running style, and (h) posture, as well as psychological and anatomical factors.

The literature investigating the effects of flexibility on hamstring muscle strain revealed contradictory results. Many studies found hypoflexibility of the musculotendinous unit may limit the muscles' ability to elongate, potentially leading to muscle strain (Jonhagen et al., 1994; Wang et al., 1993; Worrell et al., 1991). However, other studies do not support the influence of flexibility in hamstring muscle strain (Ekstrand & Gillquist, 1982, 1983; Hennessy & Watson, 1993; Liemohn, 1978; Mangine et al., 1990; Rudy, 1986; Stephens & Reid, 1988).

There was general agreement in the literature that lack of strength plays a major role in predisposing hamstring muscle strain. Researchers (Burkett, 1970; Ekstrand & Gillquist, 1983; Gilliam et al., 1979; Heiser et al., 1994; Jonhagen et al., 1993; Liemohn, 1978; Mangine et al., 1990; Rudy, 1986; Work, 1975; Worrell et al., 1991; Yamamoto, 1994) examined strength by (a) conducting tests of torque values, (b) examining bilateral strength differences, and (c) calculating the ratio of hamstring to quadriceps. These investigations suggested that no bilateral strength difference should exist between the right and left hamstring greater than 10%. Overall, the researchers tended to agree on the concept of strength and its relationship to muscle strain, but conflict on the actual H/Q ratio cutoff point.

The ratio of the H/Q was another strength variable examined for its contribution to hamstring muscle strain (Burkett, 1970; Christensen & Wiseman, 1972; Liemohn, 1978; Stephens & Reid, 1988; Yamamoto, 1993). Researchers examined the H/Q ratio in many different groups of athletes. The investigators

(Davies, 1988; Fried & Lloyd, 1992; Gilliam et al., 1979; Grace, 1985; Heiser et al., 1984; Rankin & Thompson, 1983; Shankman, 1976; Yamamoto, 1993) recommended ratios of 0.60 to 0.70 to prevent hamstring muscle strains. Some studies show that athletes who meet this critical value do not sustain hamstring muscle strains (Burkett, 1970; Christensen & Wiseman, 1972; Heiser et al., 1984; Yamamoto, 1993). Researchers examined ratios at different angular velocities and results indicated that as the speed increased, the ratio increased (Gilliam et al., 1979; Mangine, 1990; Morris et al., 1993; Rankin & Thompson, 1983; Read & Bellamy, 1990; Stafford & Grana, 1984; Worrell et al., 1991; Yamamoto). The faster the angular velocity, the more the activity was similar to functional speeds. From the literature, there was some indication that athletes who fell below this ratio still may not sustain strain (Stephens & Reid, 1988). This supported the perception that individual strength was specific to the demands required by the sport in which one participates. Stafford and Grana stated H/Q ratios may be specific for different sports or classes of sports.

Many authors suggested muscle fatigue as a factor associated with hamstring muscle strain (Agre, 1985; Ekstrand & Gillquist, 1983; Heiser et al., 1984; Rudy, 1986). One study showed that subjects who failed the fatigue test isokinetically later sustained hamstring muscle strain (Rudy). The conclusion appeared to be that injuries that occur late in an event may be the result of muscle fatigue of the hamstrings.

Inadequate pre-exercise warmup was considered to be associated with hamstring muscle strain (Agre, 1985; Safran et al., 1988; Smith, 1994; Williford et al., 1986). A proper warmup prepares the contractile properties of the tissues to handle the stresses placed on them. With proper warmup activities, metabolic changes take place increasing tissue temperatures, reducing the incidence of hamstring muscle strain.

Researchers associated poor running style and posture with hamstring muscle strain (Agre, 1985; Cibulka et al., 1986; Hennessy & Watson, 1993; Muckle, 1982). Poor running style, although not well defined, places abnormal stresses on muscle tissues which may lead to strain. Incorrect posture, whether it is increased lumbar lordosis or an asymmetry of the sacroiliac spines, can place stress on the hamstring muscles that eventually can lead to strain.

Researchers (Burkett, 1976; Garrett et al., 1984; Heiser et al., 1984; Muckle, 1982; Stanton and Purdam, 1989; Yamamoto, 1993) believe anatomical factors or characteristics of the hamstring muscles contributed to strain of the hamstring muscles. The main contributory factors to muscle strain were that the hamstring muscles span two joints, are innervated by two nerves, carry out a complex function, and are made up primarily of Type II muscle fibers. These may be factors that cannot be prevented.

Multiple Factor Involvement

Some researchers (Agre, 1985; Burkett, 1975; Coole & Gieck, 1987; Heiser et al., 1984; Muckle, 1982; Shankman, 1993; Worrell & Perrin, 1992; Yamamoto, 1993) believed that more than one factor predisposes an athlete to hamstring muscle strain. Yamamoto stated four parameters that correlate with the occurrence of hamstring muscle strain: (a) the ratio of the maximum voluntary isometric contraction torque per body weight, (b) the ratio of the strength of the hamstrings to strength of the quadriceps, (c) the bilateral imbalance of the knee extension index, and (d) the hip flexion imbalance index. In 1992, Worrell and Perrin developed a theoretical multifactor model of hamstring muscle injury. It stated that the factors of (a) strength, (b) flexibility, (c) warmup, and (d) fatigue are related to, rather than responsible for, hamstring muscle strain. There were no observable consistencies or trends other than support for the fact that some hamstring muscle strains involve multiple factors. The lack of a tread may indicate hamstring muscle strains may occur with a variety of combination of factors.

Practical Applications for Hamstring Muscle Strain Prevention

There are several recommendations for prevention of hamstring muscle strain. Prevention starts with an evaluation of the athlete and the demands of the particular sport in which they participate. This investigation studied many factors and their contribution to hamstring muscle strain. Those factors may work interactively in predisposing an athlete to strain. There must be a manner in which those predisposing factors are evaluated in determining an individual's potential for hamstring muscle strain. The practitioner may implement proper prevention and improvement strategies. Once those factors that may contribute to an individual's potential for muscle strain are determined, proper prevention and improvement strategies can be implemented. The most practical strategy is to maintain and/or improve (a) strength, (b) flexibility, (c) endurance, and (d) coordination since these factors can be examined objectively, with various devices and functional tests.

Recommendations for Hamstring Muscle Strain Prevention

From this review, a "Prescription for Hamstring Muscle Strain Prevention" was developed (Appendix B). These recommendations address the factors that are associated with and predispose an athlete to hamstring muscle strain.

These recommendations are based on the findings within the extensive review of the literature (See Table 3).

Table 3

Useful Assessments in Preventing Hamstring Muscle Strain

1. Hamstring muscle flexibility
2. Hamstring muscle strength
3. Hamstring muscle fatigue
4. Warmup
5. Poor running style / early return to activity
6. Posture

One recommendation includes a flexibility assessment where tests are performed to determine bilateral differences and abnormal ranges of motion. This problem can be corrected through hamstring stretching programs. Hamstring stretching can be performed in the basic stretching mode where the muscle is placed on stretch and held in that position for a period of 10 seconds (O'Neil, 1976).

One additional aspect to the hamstring stretch is the performance of stretching outside the normal plane of motion. The patient is in a supine position and the athletic trainer passively flexes the hip while in a slightly abducted position. Once resistance is encountered, the patient may be instructed to contract the hip extensors or flex the knee while the trainer applies resistance.

This stretch of the hamstring muscle group may be varied with changes in the angle of hip abduction and flexion. In addition, this allows manual resistance through a range of motion (J. Attaway, personal communication, September 19, 1995).

Hamstring muscle strength should be assessed through various tests. Tests include (a) manual, (b) isokinetic, (c) isotonic, and (d) isometric muscle testing. The tests will determine bilateral differences and abnormal weaknesses. If a weakness is detected, strength training programs that isolate muscle weakness and develop symmetry between limbs should be implemented.

The hamstrings muscles function as a stabilizer and a primary mover. This dynamic function of the hamstrings must be considered when addressing strength deficits. Strengthening exercises include the basic (a) manual resistance, (b) standing hamstring curls, (c) lying hamstring curls, (d) back hyperextensions, (e) reverse hyperextensions, (f) standing straight leg dead lifts, and (g) bilateral Roman Dead Lifts with the knees locked at 160° (M. Barnes, personal communication, September 19, 1995). Other exercises used to strengthen the hamstring muscle group include the (a) leg press, (b) squats, (c) step-ups, and (d) lunges (J. Attaway, personal communication, September 19, 1995).

Isokinetic strength testing allows the establishment of baseline values for athletes (Athletic Screening for Professional Football, 1988). Isokinetic tests should be performed three times a year: (a) pre-season, (b) mid-season, and (c) off-season. The parameter of interest with isokinetic testing is peak torque, representing the highest torque produced at the axis of rotation. With regard to the hamstrings, this is the torque generated with knee flexion. At 60°/sec, peak torque measures absolute strength, while at 240°/sec, peak torque measures the speed of contraction and gives a measure of endurance (Athletic Screening for Professional Football). Results of isokinetic testing determine bilateral and unilateral strength differences.

Athletic participation screening should include an assessment of muscle fatigue. Isokinetic and functional training activities can test the fatigability of the hamstring muscle group. A subjective and objective evaluation of fatigue should be determined.

Subjective evaluation for hamstring muscle fatigue involves exercise performance with the athlete giving a description as to how the muscle is feeling while performing exercises. This may include pool exercises where the water provides resistance to the hamstrings through a full range of motion. Pool exercises can be performed in various positions, and the harder you extend the hip or flex the knee with the hamstrings, the more resistance the water would apply to the patient. Other exercises that test hamstring muscle fatigability include bicycling with only one leg secured to the peddle. It is the back stroke in this exercise that stresses the hamstring muscle group and tests its endurance. Step-up exercises may test hamstring muscle endurance especially if the height of the step is high (J. Attaway, personal communication, September 19, 1995).

Objective evaluation includes isokinetic testing of the hamstring muscle's fatigability. Rudy (1986) performed isokinetic tests for muscle fatigue. At an isokinetic speed of 300°/sec, subjects performed knee flexion and extension exercises. A subject exhibited fatigue if the torque levels generated dropped below 50% of the maximum torque generated before the end of a 30-second period. If there is a display of muscle fatigability, muscle endurance training with subsequent muscle testing should be implemented.

Hamstring muscle endurance training may include a number of on-the-field sport-specific activities. Activities could range from jogging to full-speed running. One activity may include short-range bent knee running. This exercises the quadriceps and gluteal muscles, but also involves the hamstrings through stabilization. A second activity that increases muscle endurance involves running accelerations. In this activity, the patient accelerates for 50 yards. With this exercise, the athlete accelerates submaximally to a comfortable speed and maintains that speed for about 20 yards. Then the athlete should decelerate and walk 30 yards, rest, and repeat accelerations in the other direction. Another exercise may include stride running where the athlete may stride run at two-thirds to three-fourths full speed for a range of 100 yards. Stop-and-Go exercises may train the hamstrings for muscle endurance. With this activity, the athlete accelerates for 10 yards at submaximal speed, immediately stops and "back peddles" 5 yards fast, and then accelerates forward again another 10 yards. He or she would perform three to four transitions at a time (J. Attaway, personal communication, September 19, 1995).

There needs to be an assessment of the pre-exercise warmup. The warmup should include pre-activity that physiologically pre-conditions the hamstring muscles for activity. A failure to pre-condition the hamstring muscle group before activity should be determined. In the case of failure, monitored pre-activity warmup routines should be implemented.

The warmup consists of the specific exercise that will be engaged in during the athletic session, but in slow motion which allows a gradual increase in body temperature (Nieman, 1986). The general warmup involves (a) calisthenics, (b) stretching, and (c) general body movements or "loosening-up" exercises generally unrelated to the specific neuromuscular action of the anticipated performance. A specific warmup provides skill rehearsal in the actual activity for which the participants are preparing (McArdle, Katch, & Katch, 1991).

A proper warmup should (a) encompass general conditioning exercises, (b) exercises that help reach a state of neuromuscular and psychological readiness, (c) include exercises of flexibility, (d) be gradual in intensity, and (e) be sufficient in duration and intensity to raise core body temperature (Arnheim & Prentice, 1993).

The screening for potential hamstring injury should assess running mechanics through visual analysis of the running gait for improper biomechanics. An examination of the gait, as described by Stanley Hoppenfeld's *Physical Examination of the Spine and Extremities* (1976), may be performed in the assessment. In Hoppenfeld's examination of gait, any obvious limp or deformity of the extremity that may affect normal gait is noted. He described the phases and the components of each phase to help determine where the problem may occur. In addition, Hoppenfeld described the effects of muscle weakness, instability, pain, and fused joints upon normal gait. In addition, the athlete should be asymptomatic while performing activities.

A history and basic postural assessment examining curvature of the spine and spinal pathologies should be performed. The existence of an abnormal curvature and symptoms associated with lesions to the spinal column must be determined. Assessment involves (a) bony and soft tissue palpation, (b) range of motion and neurologic examinations, and (c) the performance of special tests of the spine (Hoppenfeld, 1976). If problems exist, postural correction exercises and performance of activity with correct biomechanics should be implemented.

Recommendations for Future Study

Information from this review may stimulate future research in the area of hamstring muscle strain prevention, further the examination of predisposing factors, and lead to additional research in the effectiveness of preventive hamstring muscle strain techniques. In the future, there may be investigations that examine hamstring injuries to a specific group of athletes. The researcher may examine video of the actual strain, and the preinjury condition of the athlete may be documented. Injury mechanisms can be isolated and evaluated. A study may examine prevention programs for effectiveness in different sports including both genders.

Summary

This review of the literature describes the research associated with factors and their contribution to hamstring muscle strain. As a result of the finding, medical practitioners' knowledge of these factors will be enhanced regarding predisposition to hamstring muscle strain. This study will also greatly enhance preventive approaches to hamstring muscle strains.

Preventive measures can reduce the chance of hamstring muscle strain. All attempts at hamstring muscle strain prevention will not totally remove the chance of injury; however, that chance can be reduced with a complete understanding of all factors related to hamstring muscle strain.

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Appendixes

APPENDIX A

Summary of topics discussed in recent studies (1970-1994) by author

Author(s) / Year	Flexibility	Strength	H/Q Ratio	Ecc Contraction/ Fiber Composition	Fatigue	Warmup
	TOPICS					
Agre (1985)	*	*				*
Burkett (1970)	*	*	*			
Burkett (1976)						
Cibulka et al. (1986)						
Christensen & Wiseman (1972)	*	*	*			
Coole & Gieck (1987)	*	*			*	
Davies et al. (1981)		*	*			
Ekstrand & Gillquist (1982)	*					
Ekstrand & Gillquist (1983)	*	*			*	
Fried & Lloyd (1992)			*		*	*
Garrett et al. (1984)				*		
Garrett et al. (1989)						
Gilliam et al. (1979)		*	*			
Grace (1985)		*				
Heiser et al. (1984)		*	*		*	*
Hennessy & Watson (1993)	*					
Jonhagen et al. (1994)	*	*				
Klein (1971)	*	*				
Liemohn (1978)	*	*	*			
Lysens et al. (1984)						
Lysholm & Wiklander (1987)						
Mangine et al. (1990)	*	*	*			
Morris et al. (1983)		*	*			

Summary of topics discussed in recent studies (1970-1994) by author

Author(s) / Year	TOPICS					
	Flexibility	Strength	H/Q Ratio	Ecc Contraction/ Fiber Composition	Fatigue	Warmup
Muckle (1982)		*				
O'Neil (1976)						
Parker et al. (1982)		*	*			
Rankin & Thompson (1983)		*	*			
Read & Bellamy (1990)		*	*			
Rudy (1986)	*	*			*	
Safran et al. (1988)						
Seward et al. (1993)						*
Shankman (1993)						
Simonsen et al. (1985)						
Smith (1994)	*					*
Stafford & Grana (1984)		*	*			
Stanton & Purdam (1989)				*		
Stephens & Reid (1988)	*	*	*			
Sutton (1984)	*	*		*		
Wang et al. (1993)	*					
Williford et al. (1986)						*
Work (1975)		*	*			
Worrell (1994)	*	*			*	*
Worrell & Perrin (1992)	*	*			*	*
Worrell et al. (1991)	*	*	*			
Yamamoto (1993)		*	*			

Summary of topics discussed in recent studies (1970-1994) by author (cont.)

	TOPICS			
Author(s) / Year	Mechanical	Psychological	Epidemiology	Prevention
Agre (1985)	*			
Burkett (1970)				
Burkett (1976)	*			
Cibulka (1986)	*			
Christensen & Wiseman (1972)				
Coole & Gieck (1987)				
Davies et al. (1981)				
Ekstrand & Gillquist (1982)				
Ekstrand & Gillquist (1983)				
Fried & Lloyd (1992)				
Garrett et al. (1984)				
Garrett et al. (1989)	*			
Gilliam et al. (1979)				
Grace (1985)				
Heiser et al.(1984)	*			
Hennessy & Watson (1993)	*			
Jonhagen et al. (1994)				
Klein (1971)				
Liemohn (1978)				
Lysens et al. (1984)	*	*		
Lysholm & Wiklander (1987)			*	
Mangine et al. (1990)				
Morris et al. (1983)				

Summary of topics discussed in recent studies (1970-1994) by author (cont.)

	TOPICS			
Author(s) / Year	Mechanical	Psychological	Epidemiology	Prevention
Muckle (1982)	*			
O'Neil (1976)				*
Parker et al. (1982)				
Rankin & Thompson (1983)				
Read & Bellamy (1990)				
Rudy (1986)				
Sanfran et al. (1988)				
Seward et al. (1993)			*	
Shankman (1993)	*			
Simonsen et al. (1985)	*			
Smith (1984)				
Stafford & Grana (1984)				
Stanton & Purdam (1989)				
Stephens & Reid (1988)				
Sutton (1984)	*	*		
Wang et al. (1993)				
Williford et al. (1986)				
Work (1975)				
Worrell (1994)				
Worrell & Perrin (1992)				
Worrell et al. (1991)				
Yamamoto (1993)				

APPENDIX B

Prescription for Hamstring Muscle Strain Prevention

The following may be implemented during pre-season/pre-competition screening

1) Assess Flexibility

Perform: Flexibility tests
1. Sit-and-reach tests
2. Active Knee extension test
3. Straight leg raise test

Determine: Bilateral differences and abnormal ranges of motion

Implement: Hamstring stretching programs

2) Assess Strength

Perform: Strength testing
1. Manual muscle testing
2. Isokinetic testing
    a. Torque evaluation
    b. H/Q ratio evaluation
    c. Eccentric muscle testing
3. Isotonic/Isometric testing

Determine: Bilateral differences and abnormal weaknesses

Implement: Strength training programs that isolate and address form of muscle weakness and develop symmetry between limbs

3) Assess Muscle Fatigue

Perform: Tests that fatigue the hamstring muscle group
1. Isokinetically
2. Training activities

Determine: Subjective - Feeling of muscle being fatigued
Objective- Isokinetic testing (peak torque falls below 50% of max. torque within a 30-second period)

Implement: Muscle endurance training with subsequent muscle testing

4) Assess Warmup

Perform: Adequate pre-activity physiological warmup addressing major (hamstring) muscle groups

Determine: If there is failure or inadequate preconditioning of hamstring muscle group before activity

Implement: Monitored pre-activity warmup routines

5) Assess Poor Running Style/Early Return to Activity

Perform: Visual analysis of running/walking gait for improper biomechanics. Analyze absence of any residual pathologies

Determine: If there are any abnormal gait biomechanics or continuation of residual pathologies from previous injury.

Implement: Proper running biomechanics

6) Assess Posture

Perform: History and basic postural assessment examining curvature of the spine and spinal pathologies

Determine: Abnormal curvatures (excessive lordosis) and existence of symptom associated with lesions to the spinal column.

Implement: Postural correction exercises and performance of activity with the correct biomechanics